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# PERFORMANCE BASED FIRE SAFETY

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## 1. INTRODUCTION.

In recent years there has been significant activity in the fire safety field in the areas of performance codes and other forms of performance prediction in fire safety decisions. In many nations there are in existence building codes or regulations that are based on a performance concept. Japan is a leader in this area. There, also, are important others. The United States has held many conferences on the subject and developed several concepts but to date no major jurisdiction or code authority has adopted a total performance concept. The world wide effort has been documented in numerous papers and conferences. Some of the most informative include papers by Wakamatsu[1]; Bukowski[2]; Bukowski and Tanaka[3]; Bukowski and Babrauskas[4]; Meacham[5]; and Yamada[6]. The purpose of this paper is to categorize the approaches in the author's view of a useful manner and highlight the elements needed for confident application.

## CATEGORIES OF CODE APPROACHES

A review of the approaches currently in use or development shows that the term "performance" does not have a single meaning. Each nation or entity that has adopted a performance methodology has used or developed an approach that the proponents feel best meet their needs. It is felt useful to group fire safety code approaches in five overlapping categories. While these groupings are not absolute nor fully mutually exclusive they provide a basis for examining an existing approach or guiding the development of a new one. The suggested categories are:

**Specification Code.** In a true specification code the allowable design methods are each individually specified in terse on dimension, materials, construction methods and other features. While almost all modern coeds are no longer rigid specification codes, many contain detailed specification components such as the common U.S. requirements for stair construction. Many codes also incorporate by reference specification documents such as the standards for sprinkler or fire alarm installation or the electric system installation.

**Component Performance Code.** In a component performance code the performance requirement of individual building systems or components (e.g. doors, fire resistance of framing, smoke control systems) is stated. In a component performance code there is no allowance for considering the value of one component as a justification for adjusting the performance requirement of another component. The user may install any item or system that meets the stated performance. In the U. S. the concept of performance and the movement from specification codes to component performance codes (then called performance codes) took place through the late 1940's into the 1950's. The key research document triggering this was the National Bureau of Standards document BMS92[7]. Even so most current U. S. building codes have major component performance elements mixed with elements that are still specified in detail. These codes all have some type of general equivalency clause that allows alternative approaches that produce results as safe as explicit conformance with the code, but there are few established methods to accomplish this.

**Environment Performance Code.** The term environment as used herein addresses the total fire produced environment in a building (e.g. hot gases, radiation, flashover, non-thermal combustion products.) In a pure environment performance code there are no restrictions on the methods used to provide safety so long as it is demonstrated that the fire produced environment can not exceed specified conditions. A typical environmental specification might limit the maximum temperature in a space to 100°C and CO to 10,000 ppm. While environment performance codes are not in use in the U.S. environment performance is frequently proposed by designers and their fire protection engineering consultants when seeking acceptance of an alternative approach that is not specifically allowed by the ruling code or standard.

**Threat Potential Code.** In a threat potential code there are no restrictions on the methods used, provided it is demonstrated that a specified harm to life, property, or other value will not occur given design fire conditions. In terms of life safety this approach can consider the impact of occupant mobility. There are strong elements of this approach in the Japanese performance concepts. As with an environment performance code, this approach assumes that a serious fire has occurred. Sound analysis usually involves conducting a series of scenarios representing a spectrum of potential exposures.

**Risk Potential Code.** A risk potential code attempts to measure the cumulative risk of harm rather than the potential of individual scenarios. The risk approach does not attempt to identify a specific serious or design case scenario. Rather it attempts to identify all significant scenarios their potential impact and their frequency of probable occupance. The sum of the products of impact and frequency is a measurement of the risk of harm incurred in the use and operation of the facility. Both the Australian[8] and Canadian[9] performance approaches are risk based. In these approaches the use of selected fire scenarios and the application of modeling and other modern fire physics are integrated into the determination of impact. Fire incident statistics are used as the underpinning for frequency analysis. Earlier approaches to performance based on risk most notably the

GSA Goal-Oriented Systems Approach to Building Firesafety[10] and the successor adaptations developed by Fitzgerald and his colleagues[11],[12] are based primarily on judgement approaches derived from fire history and the expertise of the users. Fire physics and fire modeling are not excluded from these methods but are primarily used to assist and justify the impact and probability judgements made.

## APPLICATION FACTORS

The successful application of Environment Performance, Threat Potential or Risk Potential code approaches all depend on:

1. Selection of the proper fire scenarios. For the first two approaches it is essential that the fire scenarios represent the realistic severe threat. In most cases a number of senecios will be required to make an adequate evaluation. For the third case it is necessary to include every scenario that can cause significant harm and those other scenarios that are both frequent in occurrence and capable of measurable harm.

2. Choice of Representative Fires. Given the current state of fire prediction science, it is necessary for each scenario to define the rate of heat release and other characteristics of the potential fire. At some future date (but not at this time) a it may be possible to model the exposing fire with sufficient confidence to derive the actual fire source input and response from the properties and arrangement of the building and it contents. As long as the description of the source fire is an arbitrary entry, the choice is critical. In the cases of environment performance or thereat potential codes the select a fire that is more the mean than extreme faults the safety of the facility by not considering the impact of serious though rare situations. Conversely, if the very maximum possible fire threat is considered, the resulting requirements can be excessive, massively exceeding that currently widely accepted in practice. A reasonable target may be to base the fire on the most sever expected potential given reasonable and common use of the facility. In the case of a risk potential approach the user must decide which extremely sever fire conditions are sufficiently within the realm of possibility to be included and which are so remote as to be ignored.

3. Selection of Models and other Computation Means. In selecting the computational method the user must either select that are sufficiently comprehensive to fulfill the objectives of the approach being followed or use specific conservative specification requirements or other means to fill the gap. At the end of the analysis the code authority or other impacted person must be able to address the full question being asked, such as is the building satisfactory safeguarded. The models selected need also to be accepted and competent. Frequently, a performance method is assembled using a specific battery of models. In such case there

is a danger of assuming that the models meet the need without sufficient analysis to assure that the full universe of the problem is being addressed.

<u>4. Uncertainties/ Safety Factors.</u> The uncertainties, leading to the need for factors of safety fall into two basic types.

a. Uncertainties in the Science. The state-of-the-art of fire science and the development of models is an emerging rather than an established science. Both the quantification of the physical relationships and the measurement of the material properties and other input data have made significant and worthy advances in recent years. There are still, however, important unknowns and measurement problems leading to uncertainties the can be cumulative.

b. Uncertainties in Life Cycle (of the Facility). As the facility is erected and as it is used there are uncertainties in terms of the workmanship of construction, the details of the actual (as opposed to expected) use of the facility, the maintenance of the facility (including fire safety features), and the specific arrangement of physical features (e.g. doors, windows, fans, fuel configurations, occupants) at the time of a fire.

The resolution of uncertainties can be addressed by:

a. Worst Case Analysis. In this approach it is assumed that all features that may fail are in their failure mode and the worst case fire occurs. All computations are assumed at the poorest performance level indicated by uncertainties in the physics involved. This extreme case is normally reserved for situations where a national or at least area wide tragedy is potential in case of fire. For example nuclear generating stations.

b. Element Safety Factors. In this approach each element of threat (e.g. fire size) is increased and each element of protection (e.g. fire resistance rating, suppression capability is reduced). The development of this type of safety factor is as good as the implementer understands the physics involved in terms of the impact of the change on the development of hazardous conditions or situations.

c. Overall Safety Factors. In this approach no safety factors are applied to individual elements but the value of the required calculated results are adjusted to compensate for uncertainties. For example in a threat potential approach the calculated time available for egress may be reduced and/or the time required for emergency movement increased. Similarly the calculated rate of application of a suppression agent my be increase or the structural fire resistance requirement increased.

d. Redundant Safeguards Approach. All codes currently include a degree of fire safety redundancy. One purpose is to protect against uncertainties in the performance of individual safeguards. One method of analyzing the degree of protection against failures due to uncertainties is to conduct parametric studies. These studies would progressively assume the full or partial failure of safeguards to determine the impact of such failure. In this concept a reasonable degree of safety should remain with the failure of any single safeguard. In most cases several safeguards should be removable without catastrophic consequences.

<u>5. Acceptability of Performance.</u> Each approach involves a difference set of performance criteria.

a. Specification Code. Exact conformance with the specified requirements. At the construction stage of a building all code will be reduced to a set of specification instructions to the workmen.

b. Component Performance Code. The code include the performance requirements of each component where performance is allowed. Acceptability is based on a mixture of submission of materials and arrangements shown to meet he component performance and the exact conformance with specification elements in that code.

c. Environment Performance Code. The code documentation needs to specifically state the acceptable environmental conditions. Acceptability is base on demonstration that the listed conditions are not exceeded.

d. Threat Potential Code. Acceptability is base on demonstration that the threatened persons, property, or operational capability will not be harmed in the design case senecios.

e. Risk Potential Code. Acceptability is based on demonstration the potential of harm will not exceeded a specified level in a given exposure time. The requirement may be in single terms (e.g. the potential of death of any occupant) or distributed terms (e.g. the potential of death versus the number of deaths).

In many cases the level of performance required by a performance code is determined by developing the performance measuring system and then using that to measure the type of facility allowable by the current code. This is assumed to represent the current level of public desire.

## CONCLUSIONS

All of the above approaches to performance codes are useful and in current use. In the authors opinion the most viable approach, at this time is a code based on Threat Potential allowing the use of any acceptable analytical method proving performance equal or better than the existent code or regulation. It is also felt that the most workable approach to uncertainty at this time is parametric studies to demonstrate failure safeguarded performance through redundancy.

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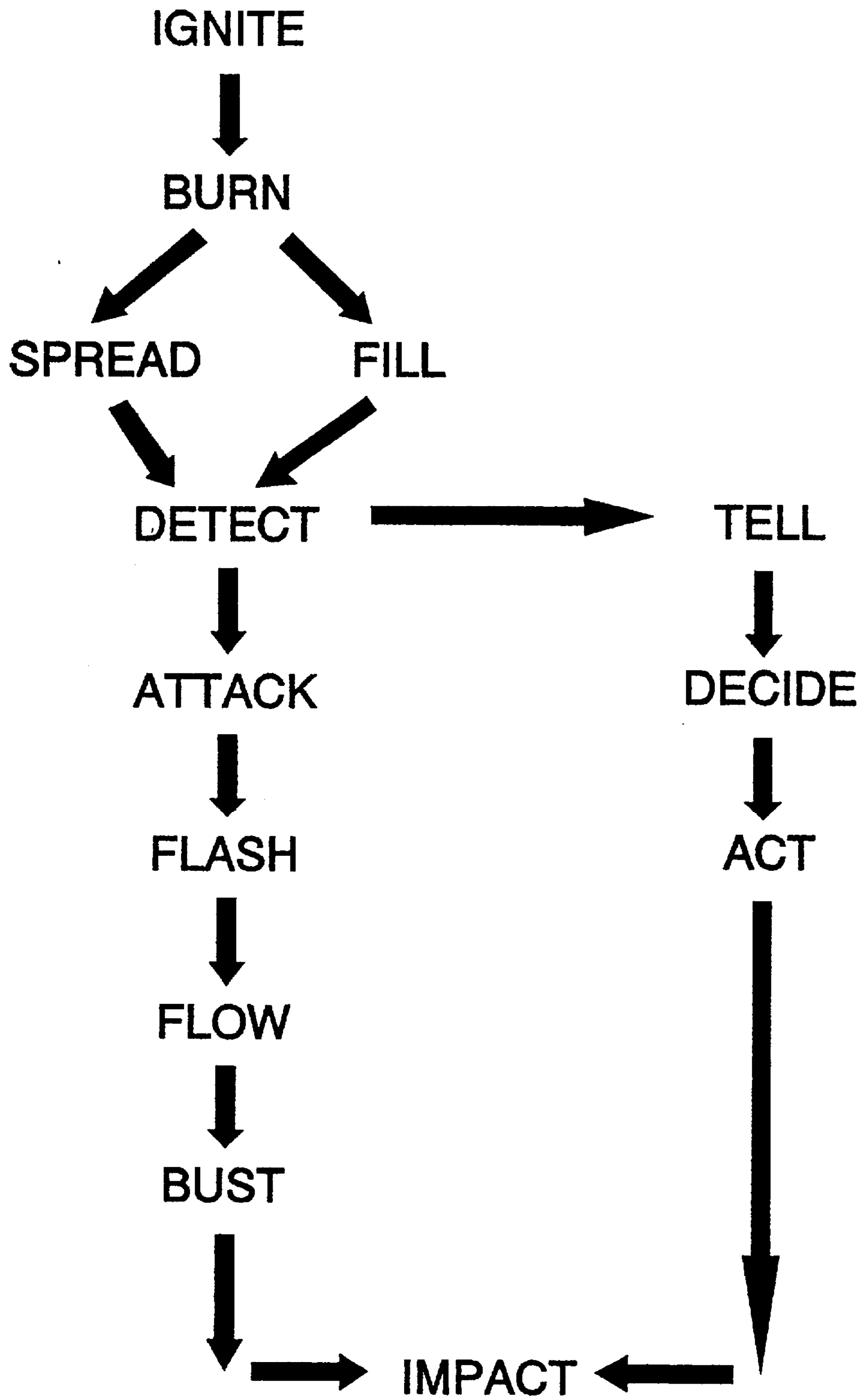
| Approach | Level of Safety | Flexibility | Cost/ Effectiveness | Responsiveness to Overall Life Safety and Other Goals | Presentation Form of Results | Responsiveness to Building Technical Advances (and Innovation) | Implementation Effort and Talent Level |
|---|---|---|---|---|---|---|---|
| Specification Code | Not normally stated.<br>Judgement based.<br>No analytic measurements. | Limited to detailed alternatives. | No ability to vary from rigid requirements to improve cost benefit. | Undeterminable.<br>Goals not stated. | Conformance - not quality is only measurement. | Resistive | Simple (Cook Book) Application |
| Component Performance Code | | Limited to the a component or a detailed alternative. | Limit range of options allows some cost benefit optimization. | | | Limited to advances within a component. | Special technicians and information desirable. |
| Environment Performance Code | Indirectly set in terms of maximum allowed conditions. | Broad but limited to a space by space analysis. | Increases ability to increase cost benefit due to increase in available options. | Depends on accuracy in selection of maximum allowable conditions. | Results are determined by models & other science that predict the potential environment in terms of the specified allowable conditions. To that extent results are fully measurable. | Readily responsive to innovations so long as both the impact of such innovations affects the specified allowable concentrations and the established measurement method can determine that impact. | Requires competent engineering capabilities and either a consensus or sound judgement on selection of scenarios. |
| Threat Potential Code | Potentially can measure level of safety in terms of the ability to assure a specific limitation of harm for an assigned "design case" scenario of physical and human conditions. | Provides broad capabilities that can be determined on a building wide as well a compartment basis. | High level of ability to measure and provide for safe allowance of cost effective innovations. | Can directly measure the achievement of safety for the selected design case scenarios. Reasonable analysis requires multiple scenarios. | Results as based on both fire development and human behavior modeling. Predication is in terms of harm given the specified scenarios. | Very responsive to innovations that relate to the potential of harm given the occurrence of the specified scenarios. Unresponsive to fire prevention innovations. | Requires competent engineering capabilities and either a consensus or sound judgement on selection of scenarios. |
| Risk Potential | Measures the probability that any specified type of harm (e.g. life, property of productivity for a specified period of exposure. | As flexible as science and data allows. | Maximum potential for cost effectiveness. | If goals are expressed in risk terms and needed data are available. | Results are in terms of harm potential. | Very responsive to innovations of all types. | Requires competent engineering capabilities. |

# ELEMENTS OF FIRE HAZARD ANALYSIS

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ELEMENTS OF FIRE HAZARD ANALYSIS
H. E. NELSON, Revised 7/26/95

IGNITION — The application of heat to a combustible material in sufficient quantity for a sufficient time to raise he material to its ignition temperature (assumes sufficiency of an oxidizer). Key engineering data include ignition temperature, critical ignition flux, incident flux and thermal inertia.

BURN — The sustained continuation of the combustion process. It may be with or without external flux. The ability to return sufficient energy to the source fuel is critical. Key engineering data include thermal inertia, incident flux, heat of combustion, heat of gassification, and non-thermal products of combustion.

FILL — The collection of products of combustion in a room or other entity as a result of the burning process. Key engineering data include rate of heat release, thermal inertia of the bounding surfaces, natural and powered vents, size and shape of the space.

SPREAD — The increase in the area of fire involvement. This may be by spread over a surface of a fuel item or by transfer of ignition from one item to another across a space. The spread of fire is a form of successive ignitions. Key engineering data is ignition temperature, critical ignition flux, thermal inertia, incident flux from the exposing flame or other hot body, and flame gas dynamics (expressed by the factor $\Phi$.)

DETECT — The discovery of the fact of fire by whatever means. From an engineering standpoint, the most interesting are those involving automatic detection. Key engineering data include rate of heat release, plume entrainment, heat losses to surfaces, heat transfer to detection devices, rate of detectable not-thermal product production, product reactions, movement of detectable products, and detection device characteristics.

ATTACK — Those actions that are intended to terminate or mitigate the act of burning. The most common are based on water but many other extinguishing media can be involved. In all cases detection is a necessary precursor to attack. Key engineering data include detection method, rate of application, point or area of application, suppression capabilities, delivery system fluid dynamics, and system reliability.

FLASH — This factor is in recognition of the major importance of flashover. The transition from a free burning fire to flashover has major consequences. Key engineering factors are rate of heat release, thermal inertia of the bounding surfaces and convective energy movement through vents.

FLOW — The movement of fire products from the point of fire origin to other spaces near and far from the fire. The driving forces include the fire itself (most impacting near the source), building HVAC systems or other air movement systems, stack effect and wind. At locations remote from the fire source the relative impact on flow is generally in the reverse order of this listing. Key engineering data include sizes of openings (including cracks in some cases), flow paths such as ducts, other leakages, fan curves, wind speeds, inside and outside temperatures, building height, changes in the flow paths caused by emergency evacuation, fire fighting efforts, or the impact of the fire itself.

BUST — The impact of the fire on the structural framing and compartmentation of the building. This recognizes that the fire intensity and the time that intensity is applied can either weaken members to the point where they can not carry their load or transmit unacceptable levels of heat from the exposed to the unexposed side of a partition or other membrane. Key engineering data include the strength-temperature capabilities of the material, the load on it, the heat applied to the element and the thermal inertial of the material and any insulation protection it.

TELL — No human action can occur until the person(s) involved are informed of the need. Telling can be by signal, announcement, word of mouth, or fire indicators (smoke, heat, flame, noise, etc.). In recent years there is an increasing awareness of the importance of providing the most accurate information possible. There are many in fire and related officialdom, however, who do not trust occupants to act wisely and still prefer uninformative signals. Inherent in the TELL function is the notification of emergency forces. Key engineering datu include sound transmission factors, message composition, and alarm transmission.

DECIDE — No person moves or takes any other action until that persons decides to do so. It is assumed that every person will take the action that individual perceives necessary and best for his protection, all things being considered. This may or may not be the best for that individual's or the group's well being. Key engineering datu include form of announcements, training, warden or other guidance, preplanning.

ACT — Once a decision is made a person will act accordingly. Actions include those related to investigation, rescue, fire fighting, escape, refuge, and other actions. Engineering data include egress path data and number of individuals involved.

### *Discussion*

Howard Emmons: We are a long way from the ideal performance codes that have been proposed by you and many others. In the structural area, the effect of the current code is that the building you design will not collapse if built as designed. Of course, they don't design for the meteor hitting the building and various other extreme situations. I think, we, as fire protection people, should have an ultimate design requirement. There, of course, would still be some extreme cases for which we cannot account. I propose three statements: 1) Everyone can get out or to a region of safety, no matter where or when the fire starts, 2) There will be no collapse for some specified period of time so that firemen can very safely enter the building and make rescue as needed, and 3) a more arguable point, given fire service response in some reasonable time, the structural loss of the building will not exceed some percentage of it's initial value, say 25%.

Harold Nelson: Except for the last one, I believe you are right on and will have no problem in finding that acceptable to anybody in design or any code authority. Inherent in your structural analogy is the conception of "used as intended." In the United States, and I'm sure in other nations, there are national consensus standards stating the expected dead and live loads brought together by leading engineers in that profession. In the United States, we need such a thing in fire. One of the committees I chair, which happens to be smoke management, is attempting to write that into those standards, but that's an obscure place. With regard to your last point on loss limitation, that's an underwriter's item, in my opinion, and should be reflected in the insurance premium. In some cases, it can be very small, and some can be a write off. Certainly, if I had a small warehouse storing railroad fuses, I might just say let it go. That happens to be an example from my past.